Invited Speakers Executive Panel

Human Factors

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ABSTRACT

Driving safety can be realized through both crash worthiness and crash avoidance. Crash avoidance is to be preferred as it dispenses with damage, injuries and traffic delays. Crash avoidance can be realized through vehicle design and driver training. Simulation can play a key role in vehicle design and training, and is more likely to be applied as fidelity increases and cost decreases. Low cost simulations have a range of potential applications for the safety research, prototyping and training required to improve crash avoidance. The extent of the applications will depend on the realism, validity and cost of the simulations. Advancements in PC (personal computer) and associated technologies are dramatically reducing the cost of creating realistic virtual environments. Increased understanding of the computational requirements in simulating the vehicle operator's tasks allows enhancing the realism and validity of the sensory environment provided to the human operator. This paper discusses the general components and requirements for simulations, and the issues that influence the realism and validity of the sensory environment. Two examples are described of low cost PC based simulations. The first example is a truck simulator including full cab motion. The second example is a driving simulator that has been used in a range of research, development and driver evaluation applications.

INTRODUCTION

Simulation can provide a safe, convenient, and comprehensive environment for conducting research, development, training and certification of drivers. Traditionally the equipment and development costs have been quite high for simulations with adequate realism and capability. As the capability of PCs (personal computers) and associated technologies has increased, however, it has become possible to develop low cost simulations with relatively high end capabilities (e.g., Allen, Rosenthal, et al., 1998a). To achieve these capabilities, rich sensory information must be fed back at high update rates and with low transport delay so that the human operator's sensory, psychomotor and cognitive tasks are equivalent to those when operating the real vehicle.

Visual, proprioceptive and auditory sensory feedback can easily be provided with recent advances in low cost, PC based technology. Motion cueing presents the most expensive component of low cost simulations, but new electro-mechanical devices allow a cost-effective solution to this difficult sensory display problem. In this paper we will discuss the application of real-time, human-in-the-loop simulations, and how low cost PC technology can achieve the required sensory feedback and computational capability required for relatively high end simulation applications in safety research, prototyping and training. In particular, such low cost simulation may be the only approach for widespread application of research and safety training of critical operations that represent a high accident risk.

BACKGROUND

Improvements in crash avoidance through vehicle design require methods for prototyping new equipment and exposing drivers to new designs. How can this prototyping and training be carried out under safety critical situations that represent hazard situations appropriate to real world driving? Consider the driver/vehicle/environment system illustrated in Figure 1. Each of the elements in Figure 1 can be simulated in some sense, and in fact, in order to evaluate new roadway designs the US Federal Highway Administration is developing an Interactive Highway Safety Design Model that simulates the driver, vehicle and environment (e.g., Allen, Rosenthal, et al., 1998b). For new vehicle designs however, the response of the driver is unknown, and so driver behavior is typically the focus of research studies in which simulation can still provide for the vehicle and environment.

When vehicle designs have proceeded to prototype hardware, instrumented vehicles can be run on test tracks or public highways to evaluate equipment and driver response. However, creating and/or controlling critical or hazardous road and/or

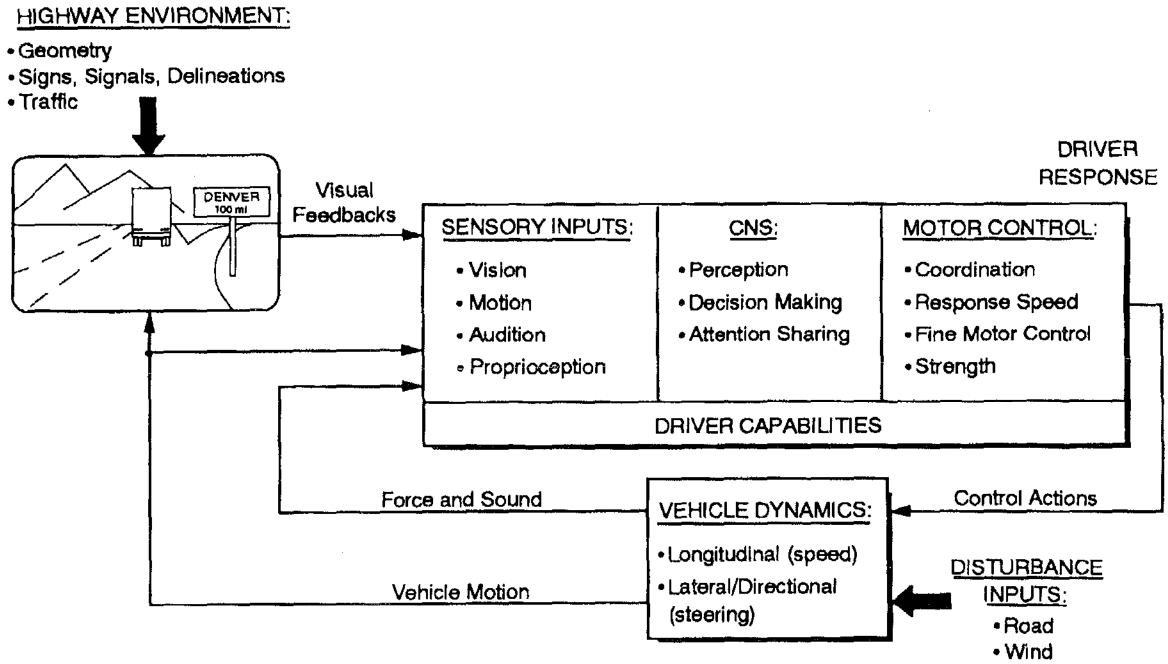


Figure 1. Driver/Vehicle/Environment

traffic situations is extremely difficult if not impossible on test tracks or in the real world (e.g., spinouts, rollover, brake fade on long, steep downgrades). Simulation can fill a critical gap for safety critical driving research and training.

The central thesis of this paper is that low cost PC and related technology can be used to reproduce realistic sensory feedback to the human operator in safety critical driving simulations. Processors, display accelerator chips and cards and operating system software advancements over the last few years permit the presentation of virtual environments that can quite adequately simulate the visual, auditory and proprioceptive cueing involved in vehicle operation tasks. Furthermore, the feedback can be provided with adequate update rates and minimal transport delays required for simulating the psychomotor and cognitive tasks typically involved in driving in complex environments.

Intel Pentium processors (i.e. 200 MHz MMX and faster) are now powerful enough to compute complex vehicle dynamics responses to the human operator's control input with adequate update rate to satisfy visual, proprioceptive and auditory cueing requirements (Allen, Rosenthal, et al., 1998a). Windows NT software allows networking several processors for increasing computational capability. Networking can also be used to allow the interaction of several simulators. Low cost PC related display technologies, including head mounted VR devices allow visual and auditory information to be provided to the human operator. Low cost electro-mechanical torque motors and actuators can be employed to provide active control loading for effective proprioceptive feedback in vehicle control tasks. These low cost capabilities are adequate to meet the requirements of vehicle control simulation as discussed below.

Graphics accelerator and sound processor cards make visual and auditory cueing practical on PCs. These cards plug into the PC bus, and can carry out complex processing without loading down the host processor. The current flock of graphics accelerator processors and cards allows reasonably photorealistic scenes to be generated at 30 Hz. Based on simple commands from the host processor, current sound cards allow the reproduction of prerecorded sounds and the synthesis of complex sounds. Control loading can be provided with low cost electro-mechanical motors and actuators. There is also a new standard for interactive game controls that give force feedback, and controllers in aircraft and driving configurations are currently available (e.g. Burdea, 1996). However, the response fidelity of this game controller standard is uncertain in terms of bandwidth and update rate as related to simulation requirements.

The basic processing requirements in a driving simulation can be described in terms of the diagram outlined in Figure 2. Here we show the human operator's closed loop control of vehicle motions through visual, proprioceptive and auditory feedbacks. The visual modality is the most important since it allows the operator to compare the vehicle's path with a desired path in the environment and make appropriate corrections. Proprioceptive feedback can provide added information about the magnitude of control inputs. Auditory feedback can provide some additional information about the aggressiveness of vehicle maneuvering and possible situation awareness. The sensory feedbacks must reach the operator in a timely fashion, after allowing for delay by the

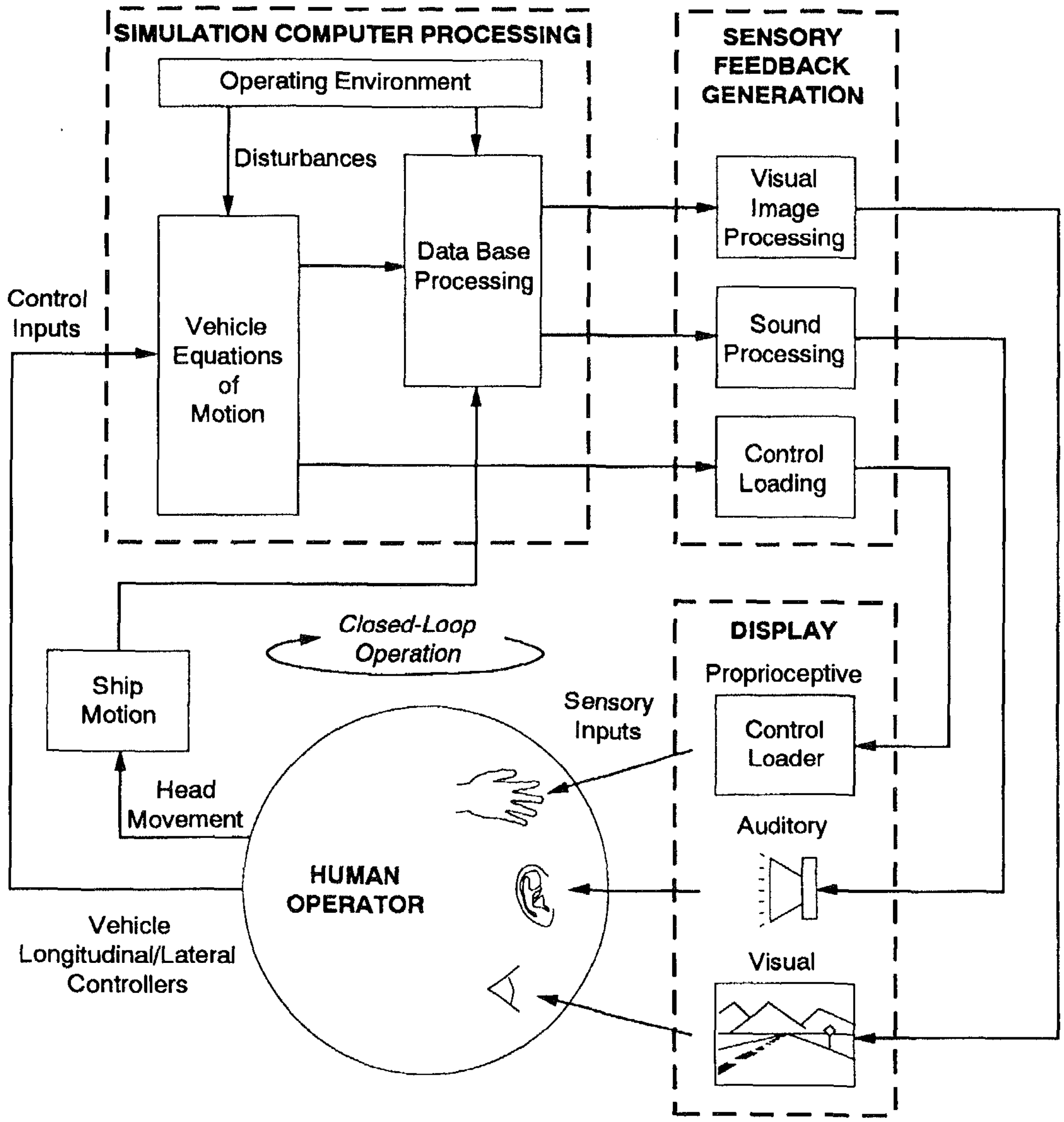


Figure 2. Basic Processing Requirements for Vehicle Operation Simulation

simulation computer processing and sensory feedback generation. Issues associated with the primary cueing modalities are as follows:

Proprioceptive (control loading) information must be returned to the human operator at the highest rate and lowest time delay of any sensory feedback in order to give realistic feel characteristics (e.g. Young, 1982). If proprioceptive cueing is dependent on simulation computer processing, update rates of hundreds of times a second with transport delays on the order of a few milliseconds are important here in order to give realistic feel.

Visual information must be returned to the human operator in less than 100 milliseconds with update motions on the order of 30 Hz or greater to give the appearance of smooth motion (e.g. movie frame rates are 24 Hz). Input sampling and processing can give delays on the order of 2 ½ frames, which result in transport delays of less than 100 milliseconds. Transport delay compensation can also be used to offset the effects of computation delay (Hogema, 1997). Resolution and quality of the visual display must be adequate for the required visual discrimination tasks. It is difficult to achieve resolutions below a few minutes of visual arc with low cost image generators and displays, so high acuity real-world tasks such as highway sign reading are difficult to simulate.

Motion feedback must correlate closely with visual simulation, so must be returned with a similar time delay (e.g., Allen, Hogue, et al, 1991 App. E). Practical, low cost platforms severely restrict motion, and so cueing algorithms have been developed to approximate the cues sensed by the human operator in the real world (e.g., Allen, Hogue, et al, 1991 App. F).

Auditory feedback has the least severe requirement for transport delay, with hundreds of milliseconds probably being acceptable. The frequency content or bandwidth of the auditory stimulus must match the human ear (on the order of 15 KHz), however, in order to produce sounds that are natural and recognizable. Doppler and stereo effects may be of importance in various driving scenarios.

Successful simulation development should include some validation procedures to verify the above response requirements and to ensure correct software implementation. Validation can include engineering methods applied to various simulator response characteristics (e.g., Allen, Mitchell, et al., 1991; Allen, Rosenthal, et al., 1992; Heydinger, Garrott, et al., 1990). The validation procedures should be designed to verify software coding and the adequate responsiveness of the various cueing dimensions.

EXAMPLE SIMULATIONS

Two examples will be given of driving simulations that each employ aspects of the low cost technology discussed above. The first application involves a truck simulation with full motion cab designed to provide low cost training and research capability. The second example involves a driving simulator that has found application in research and driver evaluation (Allen, Rosenthal, et al., 1998a). Both of these simulations have recently been upgraded with PC based photorealistic visual image generators that include graphics accelerators to provide high speed texturing, shading and lighting effects in the rendering process. The simulators have been designed for operational safety applications that cannot be accomplished in the real world with actual vehicles.

TRUCK SIMULATOR

This simulator is suitable for both research and training, and includes comprehensive software and hardware modules for providing visual, auditory, motion and proprioceptive cueing to the driver. It is currently being developed by a consortium comprised of Mack Trucks, Moog, and Systems Technology, Inc., with software provided by Renault. Figure 3 shows the system architecture provided through a combination of hardware and software. The hardware consists of an instrumented truck cab mounted on a low cost Moog electro-mechanical motion base. Instrumentation includes controls, displays, and torque feedback to the steering wheel. The visual surround is presented by a projection display system on screens at the front and rear of the cab. Stereo speakers and amplifiers provide auditory display. Intel Pentium processor based computers will handle all software operation. Cab I/O, visual image generation, sound generation, motion base and control loading commands are provided through auxiliary processor cards on the PC ISA and PCI buses.

The truck simulator software runs under Windows NT on several processors that communicate through an Ethernet link. Tests have shown the WinNTnet to be very fast (less than 2 msec delay) and very reliable (probability of a lost packet less than 10^{-5}). The software provides a variety of functions, including the vehicle dynamics, cueing commands for

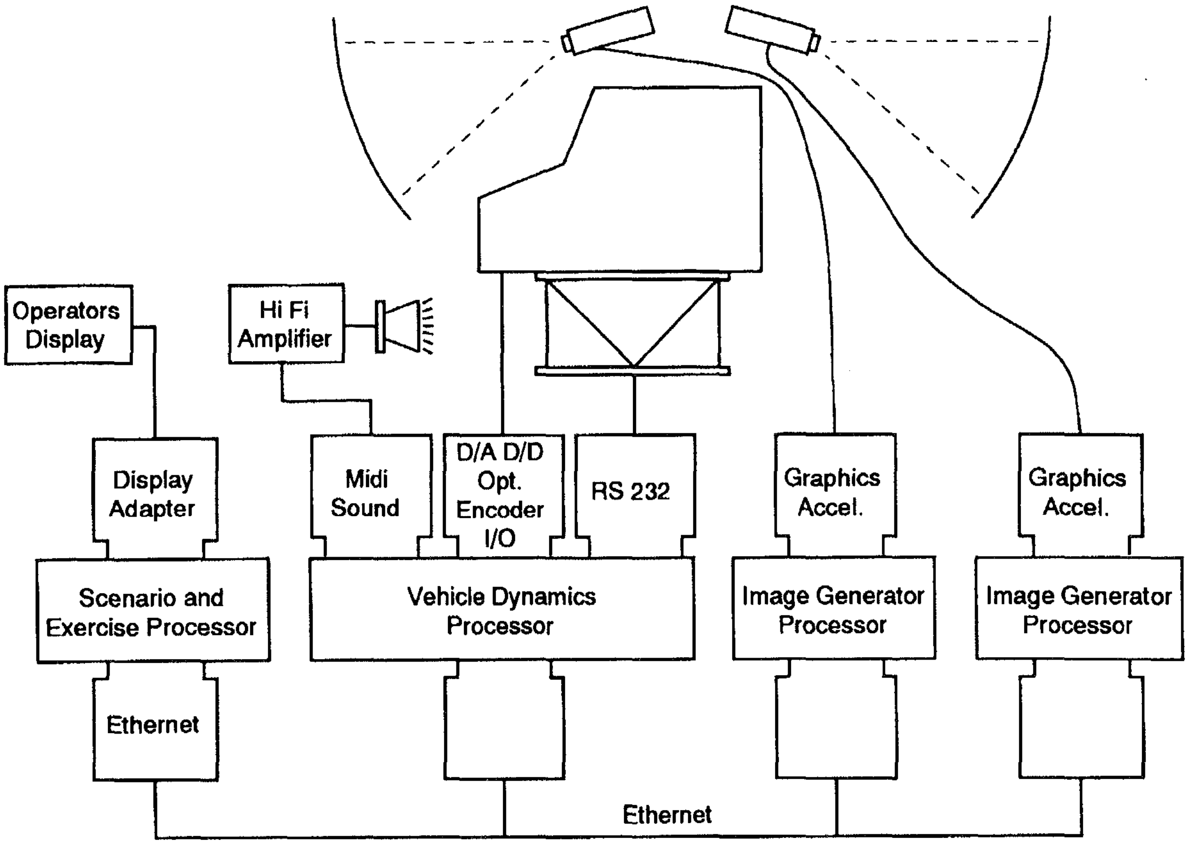
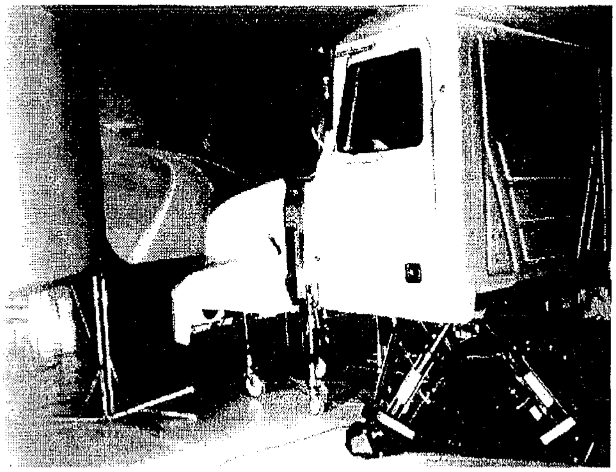


Figure 3. Truck Simulator Block Diagram

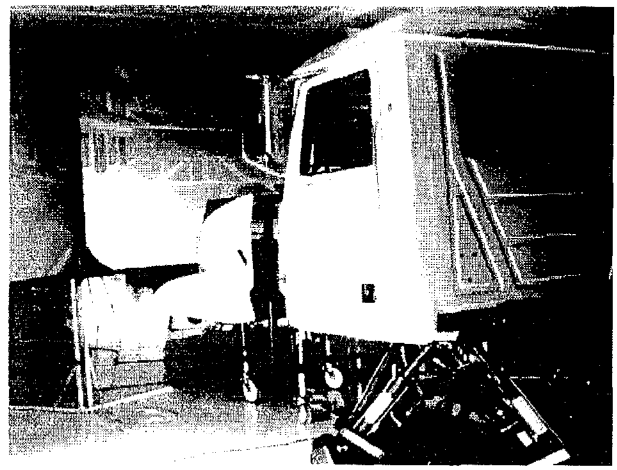
the visual, auditory, motion base and control loader systems, and other cab displays, and provides the visual data base and operator/instructor control functions. The software interfaces provide a significant opportunity for simulator variation required for research. The vehicle dynamics parameters can all be completely changed to simulate anything from light passenger vehicles to heavy busses and articulated trucks (Allen, Rosenthal, 1998a). The cueing command parameters can also be modified to achieve variations in the motion and control loading algorithms. The operator's control functions allow for changes in the visibility conditions, traffic conditions, placement on course, truckload, etc.

The IGs (image generators) consist of graphics accelerator cards running on a processor PCI bus. The cards are quite fast, and provide reasonably photo-realistic visual images at typically 30 Hz or greater update rate. The rendering speed is due to the 3Dfx graphics processor chip that has found application in video games and real-time simulation (Real-Time Graphics Newsletter, 1997). The visual display projectors are high resolution, high intensity LCD units. The sound card is a high end Midi-compliant processor, and the sound electronics and speakers is high-end consumer level surround sound equipment. The host processors are Intel Pentium Pro 200 MHz. These can easily be upgraded for additional computational power.

Some typical truck simulator pictures are shown in Figure 4. These photos portray the realistic appearance of the visual system and database, and the cab mounted on the platform. A real Truck cab (Mack CH) is provided along with actual controls and displays. The controls (throttle, brake and clutch) are instrumented with optical encoders that are interfaced with the vehicle dynamics module through an I/O card on the PC bus. The gearshift unit is instrumented with

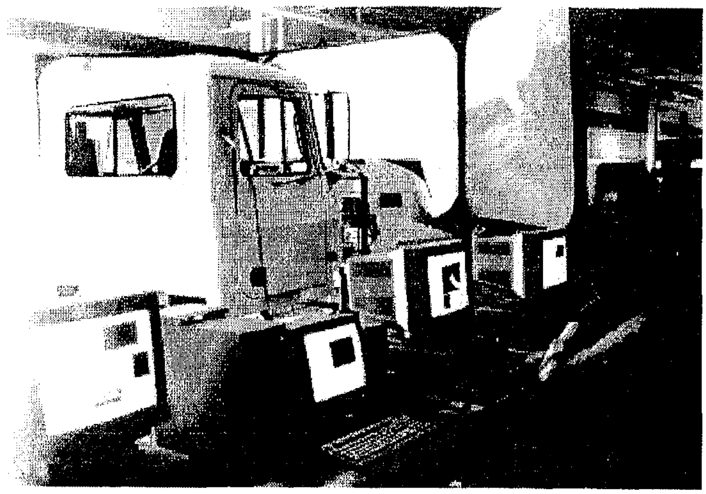


a) Cab + Motion Base on Upgrade



b) Cab + Motion Base in Town

c) Cab Controls and Instrument Panel



d) Operator's Station with Simulator PC Processors and Monitors

Figure 4. Truck Simulator Photographs

microswitches to indicate the gate and range level for gear selection. The microswitches are interfaced through a digital I/O card. The speedometer and tachometer are driven with frequency encoded signals from frequency converters commanded from D/A output channels.

Torque feedback is provided to the steering wheel by a torque motor commanded through a power amplifier from the VDM (vehicle dynamics module). Torque feel can be altered by changing parameters in the VDM associated with the steering system and power steering boost. The steer feel characteristics are correct at zero speed (vehicle stopped), and change appropriately with speed depending on the simulated boost system. The steering feel command is generated in the vehicle dynamics at a 200 Hz update rate to ensure high fidelity steering feel.

The moving base platform is an electro mechanical hexapod configuration providing full six degrees of motion. The motion platform cueing is provided by the VDM at a 60 Hz update rate. The motion cueing is designed to provide transient acceleration and attitude rate cues, combined with tilt cues to simulate sustained maneuvering accelerations.

The VDM is realized in software, and provides for the dynamics of a complete tractor/trailer rig as discussed in Allen, Rosenthal, et al. (1998a). The VDM provides for the lateral/directional and longitudinal equations of motion, and safety critical truck characteristics such as brake fade due to brake overheating on long down grades, rollover under hard cornering conditions, and jackknifing under appropriate steering and braking conditions. The VDM is computed at a frame update rate of 200 Hz, and provides cueing inputs to the IG, motion base, feel system and sound system.

GENERAL PURPOSE DRIVING SIMULATOR

This application involves complex and validated equations of motion that allow vehicles to spinout and rollover under aggressive maneuvering conditions (e.g. Chrstos and Heydinger, 1997). The equations of motion also provide a steering alignment command to a torque motor connected to the steering wheel, which provides appropriate proprioceptive feedback consistent with steering input, vehicle maneuvering, and road coefficient of friction. The operating environment includes road and aerodynamic disturbances, roadways of various alignments and interactive traffic. Sound processing with a 64 bit PC sound card can represent own vehicle sounds (engine, wind, tire screech) and sounds of interactive traffic.

Visual display can be provided by monitors, projectors, or a head mounted display. Wide-angle displays have been provide by three visual image generators with scenes projected on a 135 degree curved screen. A head-mounted display can be implemented in the same manner as described elsewhere for a parachute simulator (Hogue, Allen, et al., 1997). Typical roadway visual scenes are shown in Figure 5. Display requirements for tasks such as sign reading require resolutions on the order of 1 minute of arc. This is a difficult requirement to meet with a low cost image generator and display system. One partial solution to this requirement is to use separate high resolution but limited field of view sign generators with projected images that are optically combined with the overall roadway display (e.g., Hopkins, et al., 1997)

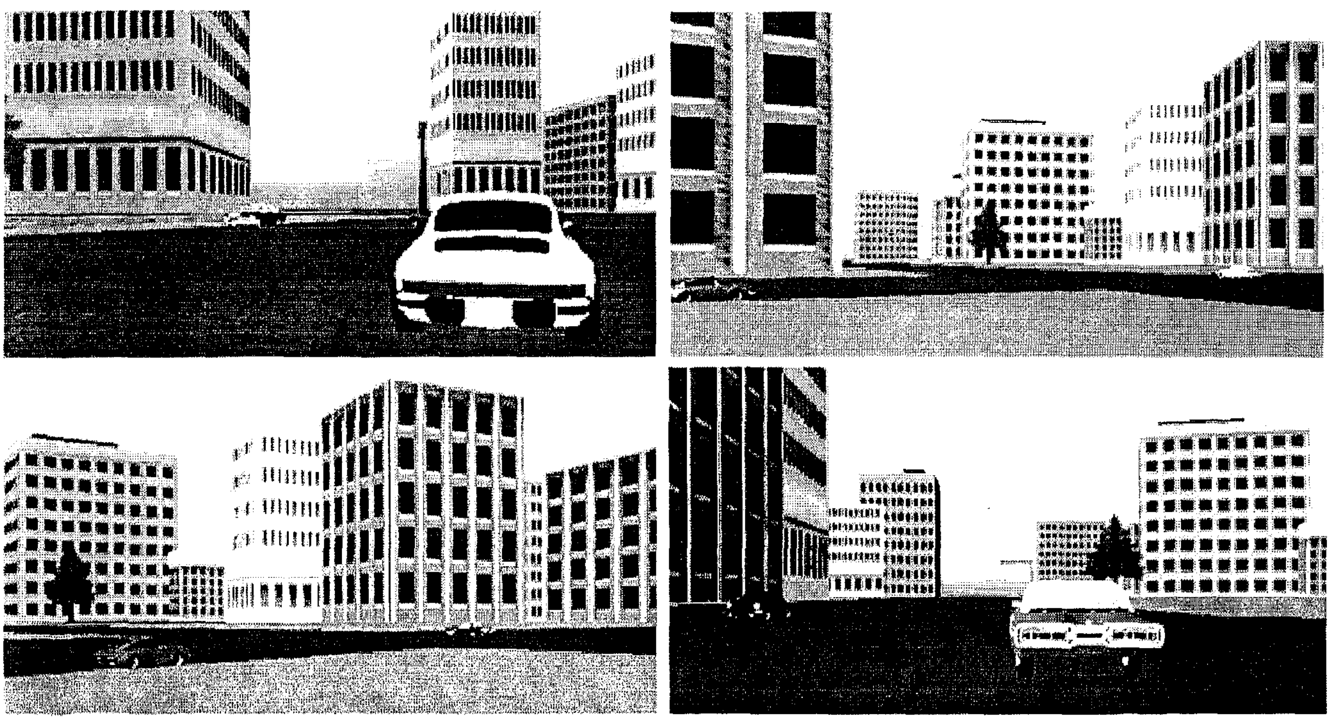


Figure 5. Typical Driving Simulator Roadway Visual Scenes

Multiple processors can be networked through the capability of Windows NT. Complex vehicle equations of motion can be run on a dedicated processor networked with the cueing command computer. Multiple visual image generators can also be run on separate processors and networked to a central cueing command processor to obtain multiple screens, wide angle and/or rear view displays. The use of a head mounted display requires only one image generator and gives a full hemisphere head field of view thus permitting drivers to look down side streets, or even over their should to view rearward scenes. A variety of physical and display configurations for the driving simulator are shown in Figure 6.

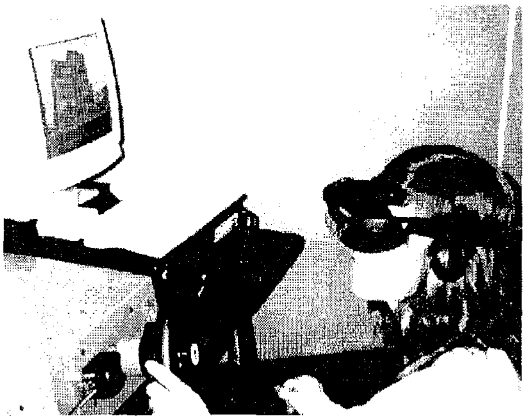
The driving simulator has been used in a wide range of research and driver evaluation applications (Mollenhauer, et al., 1994; Musa, et al., 1996; Stein, et al., 1990). Simulator sickness with single screen displays (45 degrees FOV) has been less than 5%; with the wide-angle displays the sickness rate is on the order of 10-15%. Experience with the head-mounted display is just beginning, but experience with a parachute simulator application (Hogue, et al., 1997) suggests that the simulator sickness rate will be minimal.

DISCUSSION

The success of the above applications to date indicates that low cost PC and related technology can provide useful simulation capability. Given the current speed of Intel Pentium processors and the Windows NT operating system it is quite feasible to implement a complete VDM (vehicle dynamics model) as part of a PC based driving simulator. The vehicle dynamics involved in the above driving simulator include lateral/directional and longitudinal dynamics, including driver train, steering and braking system characteristics. Even when a trailer is added to simulate a tractor/trailer rig, the VDM can still run at 200 Hz well within real time. This means that even in the most demanding of simulation conditions, a Pentium based processor can adequately handle situations such as hardware-in-the-loop applications, and high fidelity steering feel. Running similarly complicated flight dynamics should not be a problem.

Pentium processor based PCs can also adequately handle the generation of other cueing dimensions, including visual displays and sound. Graphics accelerators are available that will provide photorealistic rendering of visual scenes including texturing, lighting effects and shading. Sound processing cards can provide and mix a range of recorded and synthesized sounds, and can also include stereo and Doppler effects. Thus PCs seem poised to provide low cost driving simulation for a wide range of applications in safety research, prototyping and training.

These applications will benefit from current and ongoing developments in the PC industry as processor and graphics accelerator capabilities become faster and more powerful. Cueing devices such as visual displays and sound systems are also becoming more capable. There is also significant development occurring in electromechanical motion systems and electronic instrument panels which will improve performance and lower cost to the level that can be considered in low cost, PC based simulations.

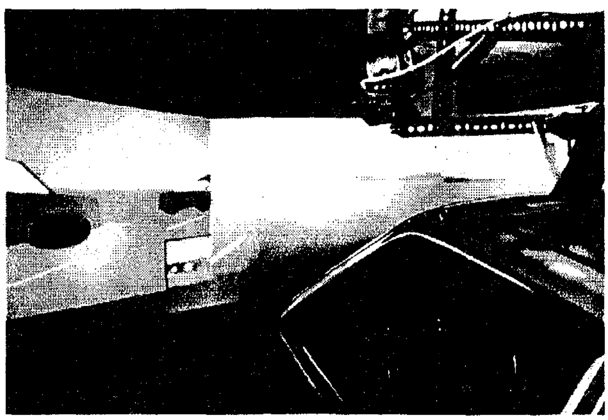


a) HMD and Game Controls

b) Torque Feel + Monitor

c) Free Standing Console

d) Game Console



e) Cab with Projection

Figure 6. Various Physical and Display Configuration for a Driving Simulator

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INTRODUCTION

Under the heading Intelligent Transportation Systems (ITS) many different types of driver support systems have been or are being developed. Generally speaking, these systems can perform any one function or combination of functions of the following options:

- provide information or warning; this can be:
    - information that is relevant for the driving task like traffic information, traffic management instructions, route guidance and warnings like collision warning or exceeding of the local speed limit etc.
    - information irrelevant to the driving task like business information etc.
- monitoring of vehicle- and driver status
- support certain parts of the driving task: this concerns concepts like ABS or traction control, the Intelligent Speed Adapter etc.
- substitute certain parts of the driving task: this concerns concepts like Adaptive Cruise Control (ACC), collision avoidance, lane keeping etc.

Apart from information that is not related to the driving task, all systems are aimed at supporting the driver by providing new functions, simplifying control operations, compensating for weaknesses in driver behaviour or impeding undesired behaviour. Theoretically, such enhancements of the vehicle's functions should make driving easier and often safer, but experience with sophisticated automation in other modes of transportation e.g. the aviation industry, alerts us to the possibility of unwanted side effects. Apart from purely technical problems, most of these side effects are caused by inadequate interaction of human controller and automated system. In order to understand why these effects occur and to prevent them in the future we need a frame of reference that provides insight into the strengths and weaknesses of human control behaviour, in this case while performing the driving task.

At this moment, a really comprehensive behavioural model of the driving task does not exist. However, a number of existing theoretical considerations can be put together to form at least a partial framework that can be used to examine possible effects of ITS. There are examples of fruitful application such a synthesis in the field of aviation where the problems concerning electronic support of the human control tasks have led to the development of Situation Awareness (SA) theories, first developed by M.R.Endsley. [Endsley 1988]

ASPECTS OF THE DRIVING TASK

Theoretical Reference Model

This Situation Awareness framework, developed originally for application to aeronautical situations, also seems suitable for application to the driving tasks since it incorporates many of the theories that have been applied to the driving task in the past.

Moreover, important existing concepts in safety regarding the influence of task load can well be accommodated in the SA framework. Therefore, the SA framework shall be used here as a general reference. In this concept, SA is distinguished on 3 levels:

1. perception of elements in the current situation
2. comprehension of current situation
3. projection or prediction of future status.

On the basis of SA on these levels decisions are taken and control actions performed.

At this point, it is important to realise that in contrast to civil aviation, where the interaction of the pilot with the aeroplane dominates the pilots tasks, the driver of a motor vehicle spends relatively little time operating the vehicle and much more time interacting with other road users. Therefore, Situation Awareness in a driver is for an important part defined as observing, understanding and predicting the behaviour of other road users. So far practically all developments in driver support systems have primarily been aimed at support of vehicle control tasks, route finding, general traffic status information etc. and not at the support of these interaction aspects. Still, since support systems can modify individual behaviour, interaction aspects must also be considered when pondering possible effects of ITS. Therefore this contribution has two parts:

- considerations regarding effects on the individual driving task (chapter 3)
- considerations of effects on traffic interaction (chapter 4).

Important Elements of the Individual Driving Task

In order to explain some of the human possibilities and limitations in a control task, we have to look more closely into the mechanisms of how the SA levels can be achieved. In the course of the last decennia, several theories have been put forward that are helpful in this respect. For instance, the multiple resource theory [Wickens] that implies that the human operator possesses a limited capacity to execute certain tasks simultaneously, seems relevant. Tasks will be executed easier (with lower task load) if certain simultaneous tasks demand separate resources. Conversely, if certain tasks compete for the same resource, problems of prioritising and sequencing tend to overload the resource.

Furthermore, cognitive information processing in human beings and subsequent action is relatively slow, a/o because of a natural minimum timelag (the neuro-muscular gap) of 120- 200 ms of processes without cognitive interference. Cognitive processing takes a variable amount of time, thereby also increasing the timelag between input (perception) and output (control action). Although the versatility of the information processing allows the operator to adapt to various process dynamics, this timelag still limits the control of swiftly changing processes. This has already been described in the 1960's by the Cross-over model [McRuer 1969], which, however, applies primarily to control behaviour in a single task. In more complex tasks, that involve more parameters and several sources of information, another limitation of the human controller becomes manifest: while multiple information can be gathered more or less simultaneously in a so-called pre-attentive state, attentive perception of multiple information sources is difficult.

Driving in traffic in general and especially in a urban surroundings, can be characterised as a process with sometimes rapid changes, a varying number of sub-tasks and multiple sources of information that are spatially distributed.

The human controller has developed a number of strategies that compensate the limitations and make effective control possible. These strategies, which are highly relevant for the interaction with support systems, can be summarised as follows:

1. *prediction*: instead of reacting to traffic phenomena after they happen, the driver tries to make short term predictions and acts on the basis of the prediction rather than on the actual situation: in this way the delay time can be compensated. This prediction requires some sort of internal model of the responses of the own vehicle and the traffic behaviour of others, given the context of the traffic situation , the traffic rules and other external conditions.
2. *piecewise modelling*: in order to make the control process fast enough its processing time must be limited. Therefore the operator seems to employ a repertoire of partial models for different traffic situations rather than a single, comprehensive, model. These models are referred to as *schemata* in the SA model. They contain a limited set of key features that are used to structure the perceived data rapidly into comprehension of the situation and also provide the basis for prediction. The schemata speed up the cognitive process, which is necessary in a highly dynamic environment, but also limit the number of perceptual parameters and relations that are processed or can be predicted.
3. *scanning and sampling*: limitations of resources and considerations of relevance of the data source cause the human operator to switch attention sequentially to those sources: the data-acquisition tasks are "chopped up" in pieces that can be processed. The attention is temporarily focused on an information input source (visual or other) which is briefly examined (sampled). Depending on the nature of the observation, the data can be used immediately or the information can be committed to memory for later evaluation. Thus, the time used to complete a scanning cycle can vary considerably and if this time tends to be too long, certain elements can be temporarily left out of the scanning sequence. This provides a means to speed up essential processing and reduce the overall task load, albeit at the cost of missing certain information
4. *simple dynamic limitation criteria*: those sources of information that can be associated with some kind of limit value (e.g. the distance to an obstacle , traffic lane boundary, etc.) will probably have a dynamic criterion for action [van der Horst],[van Westrenen]. This implies that not solely the distance to the limit is used to trigger an action but the *estimated time until the boundary will be reached.* Of course, also excess of the limit will be cause for action (but in that case it often too late!). So far, this type of dynamic limitation criteria has only been postulated for visual characteristics. In any case, this finding has implications for supportive feedback of safety criteria that current ITS concepts do not account for.
5. *automation of frequently performed task sequences*: human controllers are able to automate certain complex motoric sequences (e.g. al the actions involved in changing gears) so that a sequence can be started if necessary and run its course without requiring conscious attention. Such sequences are often called *scripts* or *skills*. Once these sequences are started they are hard to interrupt. These scripts execute quickly, are less error prone than conscious behaviour and require

much less energy. If an interruption of a script does occur somehow, remedial action usually takes a relatively long time because a cognitive analysis must be made of the interrupted state.

6. *adaptation or learning*: learning is the mechanism that has enabled the human operator to develop the previously mentioned compensatory strategies in the first place. Learning is also highly relevant to the introduction of ITS support systems: it is almost a certainty that a driver will learn to incorporate these systems in the driving strategies but how, when and to what end is less obvious and almost certainly not only dependent upon the *intended* functions of the ITS. Therefore available knowledge of mechanisms that govern learning is indispensable to an assessment of possible effects of ITS. Up to now, this has been poorly researched.

This consideration so far contains mostly task elements on the tactical and operational level and does not contain some important aspects of behaviour like the influence of motivation: attitudes and convictions and moods, the influence of drugs etc. Also the strategic level (choice of mode of transportation, time of trip, general route planning etc.) has not been addressed. These aspects are undoubtedly relevant but will not be addressed here.

SUPPORT SYSTEMS AND THEIR POSSIBLE EFFECTS ON THE INDIVIDUAL DRIVING TASK

We will distinguish safety effects on several levels of the traffic system:

A. Intended effects

B. immediate effects on individual behaviour with:

1. effects on taskload
2. controller-out-of-the-loop problems
3. effects of the Human Machine Interface
4. effects of multiple ITS devices

C. Indirect effects on traffic behaviour

D. Long term behavioural adaptation.

We will now examine these effects separately.

Intended Effects

It is of course very important to see whether the intended effects of the various devices are indeed manifest. These intended effects need not always be aimed directly at increased safety however; often devices are meant to alleviate tedious parts of the driving task (e.g. cruise control) , to facilitate otherwise cumbersome functions like route finding or to provide otherwise unattainable information (the presence of congestion further on). Increased safety is then claimed as a side effect.

First, let us consider information systems. There are not many devices that really have proven themselves in practice: only traffic management systems and Radio Traffic information of various implementation have been used on a large scale. These systems have so far proved moderately effective in achieving a higher level of safety and improving traffic flow. [De Kroes 1983],[Verwey 1996]. Other systems, like route guidance, exist on a much smaller scale and so far have not shown particular safety effects. Devices providing information *not* related to the driving task like car telephones have evoked serious doubts about their safety [Maclure 1997], [Brookhuis 1991]

Experience with other support systems derives largely from laboratory- and simulator tests and from small scale field studies (often in a well controlled environment). Many studies indicate that positive intended effects on driving behaviour are indeed detectable but rarely in a very convincing way because these effects are offset by simultaneous adverse effects. However, some devices that are currently studied seem to have a potentially large positive effect on safety. One such device is the Intelligent Speed Adapter (ISA) [Almqvist 1991],[Godthelp 1991], [Persson 1993], a device that somehow interacts with the driver to decrease the speed only when the local speed limit is exceeded. Although experiments are still under way, expectations are that the positive effects far outweigh the negative.

Generally speaking, from a theoretical standpoint, it must be possible to enhance the quality of Situation Awareness of the individual driver and simplify the driving task in complex situations without distraction and to simplify vehicle operation without out-of-the-loop effects. Learning how to emphasise these positive effects and suppress the negative ones is still a considerable challenge to researchers.

Immediate Effects on Individual Behaviour

<u>**Effects on Task Load**</u> - *Underload* - Underload is defined as the situation gets into a state of limited attention to driving (no specific driving task demands) or deactivation (dozes off).

Underload can be brought about primarily by devices that partly take over the driving task like Cruise Control, which leads to a state of lessened vigilance (see a/o Riemersma, Rumar, Wickens, Wiener and Yaouta) if combined with traffic conditions that are not demanding. This may occur in longer trips on a quiet motorway (Highway Hypnosis [Wertheim 1978]) or an other road with monotonous characteristics and especially at night.

In an urban setting, the (remaining) traffic tasks are usually such that underload can be considered no real danger. Only e.g. while tiredly driving by night in a deserted street could ITS induced underload conceivably lead to increased risk. This condition must be considered rare.

Overload - Information presentation by ITS

As indicated before, task overload is thought likely when several cognitive tasks compete for a single resource. If the tasks indeed need to be executed at practically the same time a stalemate will follow: the resource can process only one task at a time and this results in at least one task being ignored. (It should be noted that automated tasks (scripts) usually do not compete). The subject of task load associated with information presentation has been examined quite extensively a/o by Antin, Kaptein, Parkes, Steyvers , de Waard, Verwey, Wierwille, Wickens, and Zaidel.

In general, the normal array of traffic tasks are not so critical and mostly tolerate some postponement. Still, competing tasks require extra decisions concerning their priority which increases the effort required. Since it is often estimated that 90% of all information input goes by way of the visual channel the channel is considered a prime candidate to produce overload. The addition of yet another visual task by ITS applications therefore is considered undesirable. This is especially relevant in an urban setting where a large number of relevant information sources is present that all have to be scanned: a constantly changing layout of the infrastructure, a large variety of traffic signs, different types of road users from a variety of directions and generally high differences in speed (higher than on a motorway) between them all make for a highly loaded visual resource. Moreover, different traffic rules apply to different types of road user and different types of infrastructure which also makes it more difficult to choose an appropriate schema and select appropriate actions, so the "decision making" resource is also more highly loaded than on a motorway.

As remarked before, if task load increases some items are often left out of the scanning sequence. Research [Verwey 1991-1993] has shown that some ITS applications with a visual interface that do not convey high-priority information are often neglected when the traffic situation outside is demanding. This suggests that drivers are effectively prioritising their visual input. The device is only observed again when the situation allows that and the possible negative influence on safety is then small. The latter of course, only if the driver really can ignore the device: some cues, like flashing lights, prove very difficult to ignore!

We must also realise that this adaptation of the scanning cycle is only possible if the driver can access the information source whenever he/she wants it, or in other words if the task is *self-paced*. However, if the information source is located outside the vehicle, on the roadside, the driver can only access the information in a limited area (and time) before the sign is past and this is called a *force-paced* task. Other examples of forced-pace tasks are auditory displays that only produce their information at a certain moment and cannot repeat that same information whenever the driver wants it.

Generally speaking, all devices that employ force-paced tasks limit the possibilities of the driver to regulate the task load. These devices produce a higher risk of overload, especially in urban traffic!

But even if the devices are self-paced, some detrimental effects of visual displays remain detectable in the driving behaviour, like larger lateral displacement and later braking before crossings. Self-paced auditory displays show less of these effects.

Note 1: Even without inducing overload, ITS information systems can still increase the driving risk somewhat. This is due to the extension of the normal scanning cycle by the display: it can occur that , while attention is temporarily fixed on the display, an important event elsewhere is not observed. While there is no elevated taskload in this case there is still the danger of an accident due to this oversight.

Note 2: For some types of devices, urban traffic provides an escape from these difficulties: the frequent stops at traffic lights could be employed to convey certain information without endangering traffic behaviour.

ITS devices that take over part of the driving task

Many of the devices that are intended to take over part of the driving task like ACC, lateral driving support etc. are mostly intended for operation under motorway conditions. As such they have been designed to alleviate the driving task. In urban circumstances, where frequent changes of course and speed are normal, these devices should not operate, yet if they still do may cause serious complications. The driving behaviour they (more or less) enforce is often contrary to usual driving behaviour in urban traffic as expected by both the driver and surrounding road users. Constant speeds, large time-headways or a straight course are unusual in urban traffic and if the support systems are not switched off they may give rise to the driver "fighting" the automated system while neglecting the surroundings. There have been examples of such "fights" in recent incidents in highly automated civil aircraft.[Stanton &Marsden 1996]

Human-Out-of-the-Loop Problems

A specific problem with support devices that take over parts of the tasks of a human operator is associated with loss of vigilance and eventually loss of certain skills [a/o Endsley 1995].

The operator's role is reduced to supervision of the system, but the supervisory activities are often neglected or omitted entirely, thus freeing capacity for other activities

As an example of short term effects of this nature: research using driving simulators [a/o Stanton,Young & McCaulder 1997] indicates that drivers will readily adapt to anti-collision devices and will completely rely on the device after only a short adaptation period of time. If the simulated device is made to fail (e.g. it does not "see" an other vehicle) more than half of the drivers tested fail to take effective action and crash!

Again, these tests have been made under motorway conditions. In urban conditions, with a multitude of moving and stationary obstacles, failure of the automatic device is far more probable than under the relatively simple motorway conditions. This sort of adaptation could therefore prove far more dangerous in an urban setting.

Research indicates that human controllers who have developed certain skills and are then placed in a supervisory role will perform better in the previously mentioned situation than human controllers that have never developed the specific skill because they learned to work with the support system from the start. This indicates the possibility of a long term deterioration of road safety: if future generations are trained solely in vehicles with all possible support systems they will not develop the skills associated with "manual control" that are required without support or with failing support.

There is also another, long term risk involved in progressively automating human tasks, specifically when the automaton becomes more and more complex. In this case the human supervisor may construct an internal model based on partial or even mistaken understanding of the system. This can lead to either misplaced trust in the systems safety in certain conditions or to unnecessary interventions by the supervisor.

Effects of the Human Machine Interface

Many of the effects mentioned in the previous paragraphs are related to the design of the Human Machine Interface (HMI). Research in the past ten years into the HMI has provided much insight into many practical parameters that interfaces have to comply with. The results cover such items as placement of displays, contrast of the display and ambient light, use of standardised symbols and other ergonomic characteristics. Also safe limits of necessary sampling time (ca 1 s) and maximum number of samples (3) have been established for visual displays. Rather than going into all the details, it suffices here to refer to specific research [a/o Heijer 1998], some national guidelines and the new (concept of the) European Code of Practice for such an HMI. It should be emphasised however that knowledge on the subject of an optimal HMI for all sorts of functions is still far from complete.

One of the problems that still remain is, that most of the research has been carried out using a single ITS device. Guidelines usually state that criteria for single systems should also apply to multiple systems as a whole, which implies the need for a standard for integration. As things stand now, this standard is still lacking (and not to be expected soon!).

Effects of Multiple ITS

So, one of the problems with primarily commercial development of ITS devices is, that co-ordinated development does not necessarily exist. If drivers can equip their vehicles with an arbitrary selection of ITS applications, a number of different problems can arise as a result of lack of co-ordination. These problems include:

- the placement of multiple displays, making the scanning task unacceptably more complex
- simultaneous messages, with all possible mixtures of modes (visual, auditory, tactile) that arrest attention and demand time to sort out
- conflicting instructions or even actions by autonomous devices

Again, especially in an urban environment, the resulting confusion and interference with the already complex driving task must be considered highly undesirable.

Counterproductive Behavioural Adaptation

Counterproductive behavioural adaptation is the phenomenon that drivers start behaving in riskier ways as a result of a perceived increase in safety provided by an ITS device (or any other device). This is an effect on the individual level rather than an effect on traffic interactions.

These longer term effects still have not been very well researched and are often speculative. However, there are Indications that these effects must be taken seriously.

As an example, drivers of vehicles equipped with Anti Blocking Systems have shown some adaptation to the device a/o. by increased speed under adverse conditions. Introduction of ABS seems to have changed the types of accident these drivers get involved in rather than having decreased the number of accidents.

Also, experiments with an intelligent speed limiter, in this case only an advisory system, evoked adaptation. The system showed the current driving speed in relation to the local speed limit in three stages: lower than the limit, 0-10% excess and more than 10% excess of the limit. Practically all drivers adapted their speed to the range 0-10% excess, effectively homogenising their speed but also increasing their average speed, in almost all environments, including the urban. [Brookhuis]

Similar effects of automatic devices have been observed in aviation and the process industry where high levels of automation have often introduced new types of accidents due to unintended or unforeseen adaptations in human behaviour. Also, limited understanding of the complex automated processes by the operator has proven to be a source of severe errors. [Satnton & Marsden, 1996]

Indirect Effects on Traffic Behaviour

Indirect effects can be defined as behavioural adaptations on levels or modes of behaviour that are not directly related to the function(s) of ITS devices. Following a traditional model we can distinguish different indirect influences on the safety of traffic flow and on the strategic level and the tactical level of the driving task.

Influence on the Safety of Traffic Flow - Over the past decades, motor vehicles have progressed to a state where differences in handling, road holding and technical reliability between different brands have become practically irrelevant. This homogeneity allows a simplification of driver skills and also makes prediction by judging a vehicles movements more reliable. In this way, car manufacturers have effectively contributed to a marked increase in overall road safety.

The introduction of a large variety of support systems, applied in a rather random fashion may once again introduce dissimilarities between vehicles which will probably result in a deterioration of overall safety.

Influence on the Strategic Level of the Driving Task - On this level indirect effect have to do with undesired use of motorvehicles indirectly due to ITS.
One expected general effect of automating difficult or dull parts of the driving task is that driving becomes more attractive which will lead to an undesired increase in the use of motorvehicles. Another effect of ITS, or more specifically route and traffic information systems, may be a redistribution of traffic through areas where high traffic densities are not desired.

Furthermore ITS systems that improve the handling characteristics of vehicles may lead to increased use of those vehicles under adverse weather conditions like heavy rain, snow or icing.

Influence on the Tactical Level - On this level indirect influence of ITS can manifest itself as creating time or opportunity for undesired activities that are not related to the driving task. These tasks can than distract the driver to such an extent that the activity consumes more than the available extra time.

Car telephones can be considered an example of such devices: they introduce a mental task (maintaining the conversation) that is totally unrelated to driving and thereby can introduce interference with the mental processes that are vital to driving. Again this can be especially dangerous in urban areas where the traffic task is demanding.

Another example are TV devices in the car that may distract the driver from the traffic task.

Also devices intended for support of the driving task like anti-collision devices may lead to such problems: by creating "free time" for certain tasks the driver may be tempted e.g. to be more deeply engaged in distractions like (telephone) conversations or listening to the radio.

Effects on Traffic Interaction

As stated before, the average driver spends relatively little time operating the vehicle and much more time interacting with other road users. Predicting possible behaviour of those other road users therefore features strongly in the predictive strategies described in chapter 2. Since the interactions are virtually anonymous the predictions must be made on rather superficial behavioural cues of the road user's movements and these movements can only be observed for a limited time. This means that the basis for prediction (presumed present in the schemata) must be a generalised model, an average.

If an ITS support systems somehow changes one driver's behaviour in such a way that behavioural cues do not correspond to average intended behaviour, this change will disturb the prediction of another driver and so may render the situation less safe, even if this modified behaviour is safer from a individual point of view. This is best illustrated by an example:

Figure 1 depicts a motorway situation where vehicle A overtakes a row of other vehicles. The driver of A must try to predict whether any of the other vehicles

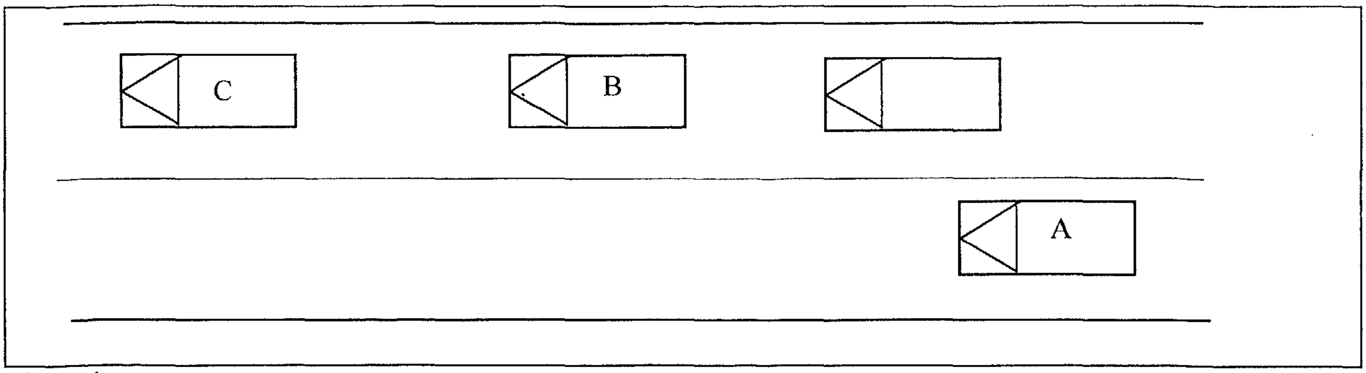

Figure 1.

will also start an overtaking manoeuvre. In this example, vehicle B is in fact preparing to overtake C. Normally, this intention is communicated by a narrowing of the gap between B and C (the flashing direction indicator is usually only used at the last moment and has no predictive value!). Now, if B should be equipped by ACC, the vehicle will probably not display this cue, since the automatic system maintains a constant headway. Of course, the driver of B may override the ACC system and still display the usual behaviour, but it is far easier to let the system take care of headway maintenance and prepare for the overtaking manoeuvre leisurely.

In this example , the driving situation is actually made safer for driver B, since the risk of colliding with C during the preparation (looking in the mirrors etc.) is effectively eliminated and the drivers taskload is also somewhat lower. For driver A however, the usual cue is absent (on the contrary: the behaviour seems to confirm lanekeeping) and the driver may be startled into an emergency reaction by unexpected overtaking of B with the associated unsafe consequences.

This sort of problem will particularly be evident during the time that only few road users are equipped with advanced support systems. The other drivers will not encounter modified behaviour often enough to adapt their strategies. Eventually, if many or most vehicles use these systems, behavioural adaptation will probably lead to the use of other cues and thereby reduce the risk again (as drivers generally seem to have done in the past 20 years).

DISCUSSION AND CONCLUSION

In the previous considerations we have tried to describe possible effects of ITS on road safety by considering possible effects mostly on tactical and operational levels of driver behaviour. We must realise, however, that although these behavioural effects may be valid, this is not completely equivalent to estimating the effects on the actual occurrence and severity of road accidents. Not every driver error will be "translated" into an accident, on the contrary: the traffic system seems quite tolerant for errors. For an important part, this may be caused by the same driver characteristics that have been reviewed: the predictive and adaptive strategies that drivers employ will also allow them to compensate failing behaviour of other drivers to a certain extent. This makes more detailed understanding of the how's and why's of these strategies all the more important, which implies that we must search for methods to measure important parameters of the internal processes more directly.

So far we can conduct a large variety of experiments and measure many details of driver externally observable behaviour but exactly how to translate these measurements into effects on actual accidents still eludes us. In fact, along with the use of these "objective parameters" the use of expert opinion, like the opinion of experienced driving instructors, is often considered indispensable to judge behavioural effects in experiments. For this reason, we cannot say that we can fully interpret or predict behavioural effects of support systems.

May be this is one of the reasons that the development of all sorts of automated systems to support or expand the possibilities of the driver so far has been dominated by technical and economical considerations which has produced systems that are primarily oriented on operational tasks of the driver. A major part of the driving task and a part that is highly relevant for safety: interaction with other road users, has received much less attention. More thorough and coherent research into this area, for instance along the lines that have developed in other modes of transportation like aviation, is necessary to avoid many of the side effects mentioned and to optimise support.

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ABSTRACT

As intelligent transportation systems (ITS) become more available, drivers must cope with increasing amounts of in-vehicle information. While the intent of providing such information is to make driving safer and more convenient, the aggregate of all this new information may paradoxically decrease vehicle safety if good human factors principles are not used to implement ITS. This paper first discusses the need for ITS integration by reviewing two major new sources of in-vehicle information: collision avoidance systems (CAS) and advanced traveler information systems (ATIS). System integration is then defined in terms of system characteristics and their effects on the driver. ATIS guidelines illustrate first-level system integration. This paper concludes with a discussion of the safety implications of ITS.

INTRODUCTION

Modern technology has enabled the development of sophisticated computer-based user support systems in a variety of industries. Such systems are available today in such diverse areas as nuclear power control rooms, commercial aviation cockpits, air traffic control centers, and surface, air, and subsurface military weapon systems. The primary aim of all these systems is to assist the users in performing their jobs more safely and efficiently. Such is also the case with the burgeoning information systems being incorporated into passenger and commercial vehicles as a result of the effort through the internationally recognized program entitled, ITS to field sophicated electronic systems to improve highway transportation.

In-vehicle information systems (IVIS) can be categorized by functional areas such as: collision avoidance, traveler information, and driver convenience. The collision avoidance technologies will address areas such as road departure, lane change and merging, rear end collision avoidance railroad crossing warning as well as advanced cruise control and drowsy driver warnings. The ATIS, which will be offered as part of the vehicles of the future, include information in such areas as routing, navigation, safety and hazard road advisories and warnings, traffic and congestion, motorists services (i.e., yellow pages information), vehicle status, weather information, and supplemental highway sign information. Commercial and transit vehicles will also include applications designed to support those vehicle's operational objectives such as cargo status, truck routing, and precision docking. Some of these systems are already available in today's vehicles.

THE NEED FOR ITS INTEGRATION

While these various collision avoidance and traveler information systems have the potential to provide useful information to the driver, they can decrease vehicle safety if they are not designed and implemented in a manner that is not consistent with driver capabilities, limitations, and expectations. For example, multiple, non-integrated CAS and ATIS displays have the potential to overload the driver's ability to properly perceive and comprehend the information being presented.

Table 1 lists the kind of in-vehicle information that can be presented with CAS and ATIS. Each topic in the table represents a medium to large set of potential messages. The total number of potential in-vehicle driver messages for all the topics in Table 1 would form a list of over forty pages. Furthermore, the manner in which each potential message could be displayed (e.g., sensory modality, display location, message priority, etc.) adds considerably to the total amount of potential in-vehicle information. It is well-known that reaction time and accuracy of human response depends upon the potential message set, rather than only upon the actual message presented (see Kantowitz & Sorkin, 1983, chapters 2-6 for elaboration of this point). Since Table 1 represents a large potential message set, there is ample room for human delay and error in responding to any such in-vehicle message.

Table 1.
Potential ITS In-Vehicle Information

• **Collision Avoidance:**	• **Advanced Traveler Information Systems:**
– Road Departure	– Trip Planning
– Rear End	– Route Guidance
– Lane Change/Merge	– Route Selection
– Intersection	– Multi-Modal Coordination
– Railroad Crossing	– Route Navigation
– Drowsy Driver	– Yellow Pages
– Automatic Cruise Control	– Automated Tolls
	– Motorist Services
	– Personal Messages
	– Vehicle Status
	– Regulatory Information
	– Travel Advisories
	– Road Condition
	– GPS

This sensory and perceptual overload can lead to cognitive confusion which would result in a decrease in effective driver performance of the primary task of driving the vehicle. With the driver being exposed to just a subset of the information listed above under collision avoidance and ATIS, the driver can easily be overwhelmed with information to where the information becomes at best, a mere distraction, and at worst, a distraction that takes the driver's attention away from the critical points in the driving task. To be effective, this information must be categorized and prioritized by the system prior to presentation to the driver if the system is to be safe and efficient. An issue that confronts the designers of sophisticated computer-based user support systems such as airplanes and nuclear plants is overwhelming the operators with information (Kantowitz & Casper, 1988; Kantowitz & Campbell, 1996). In the same manner, the vehicle designer must be able to convey to the driver which displays are primary, secondary and tertiary so a number a displays do not compete for the visual and cognitive attention of the driver. An example of a potentially hazardous driving situation could be represented by a driver who is tracking his progress on a route guidance device when his engine oil light illuminates. The driver immediately begins to slow down and initiates a merging maneuver to get to the right hand shoulder. Simultaneously, the collision avoidance system advises the driver of the vehicle in the 4 o'clock position that may be struck, while secondary warnings are reminding the driver of the critical nature of the loss of oil pressure. In addition, the route guidance system is now beginning to provide advisories that the right merge maneuver is not part of the planned routing. For these systems to function in a safe and efficient manner, they must be integrated at the vehicle level.

The discipline of human factors plays a critical role in the development of safe and efficient in-vehicle information systems. It follows the human-centered approach which essentially means that system design is predicated on user requirements, capabilities, and limitations. For instance, in reference to an in-vehicle information systems, human factors practitioners considers such questions as:

- What information do drivers need and want?
- When should the driver receive the information (i.e., message prioritization)?
- What format should the information take?
- How long should the information be displayed on the in-vehicle display?
- Which of the driver's sensory channels should be used to convey the information?
- What kind of control inputs are necessary?
- How does the current piece of information relate to other pieces of information the driver has already received?
- How does accuracy of the information affect usage and performance?
- How does the information affect the driving task?
- When and how can the driver share processing time between ATIS tasks and conventional driving tasks?

Human factors promotes the development of well-designed, fully-integrated IVIS, which filter, prioritize, and communicate driving-related information. To enable the proper integration of driver and in-vehicle information features, human factors must address a variety of issues on multiple levels (e.g., system, driver, delivery, infrastructure, research methodology, and outreach). The following discussion will focus on some of those human factors issues related to in-vehicle information systems.

DEFINING IN-VEHICLE SYSTEM INTEGRATION

From a human factors perspective, integration is defined by system characteristics and their effects on the driver. Thus, while a control engineer could easily create a list of system characteristics, such as hardware, software and functions, this list would be incomplete as far as depicting system integration because it does not include effects on the driver. Such driver effects would include workload, compatibility, and might be sufficiently complex to require formulation of a driver mental model (e.g., Levison, Kantowitz, Moyer, & Robinson, 1998, in press). System integration can be achieved only when both the characteristics of the driver and the hardware/ software provided by the system manufacturer are included.

Operational Definition of Integration

The use of the word "integration" among ITS professionals can often lead to ambiguity and sometimes to misunderstanding because it is used by different people to mean different things or it can even be used differently by the same person in different contexts. The word can be employed in regard to separate areas such as hardware, software, infrastructure, user functions, or can refer to the inclusion of two or more of these areas. Within these areas, integration can refer to the subtask, task, subsystem, system, or multiple system levels. Since the use of the term "integration" can cause confusion, a human-centered operational definition of "integration" follows. Within this context, integration is said to be complete when the user perceives one information system. Integration in this paper will be concerned primarily with driver IVIS functions and will be viewed from the perspective of the driver. For now, a laudable goal would be to have drivers perceive all in-vehicle information as emanating from one system.

ATIS Guidelines as System Integration

Integration of in-vehicle systems is a challenge for designers because they often find it difficult to determine the effects of the system on the driver until after the system has been built and deployed. By then it is too late to alter system characteristics and so better integration must await the next revision of the system. Even then, it may not be practical to change aspects of the system that reduce integration due to a desire to retain as much as possible from the first version of the system so that the next model can be deployed as quickly and economically as possible.

However, the human sub-system has known characteristics that can be anticipated during system design. Designers can use this knowledge to improve their systems before the systems are built. Human factors design guidelines for ATIS (Campbell, Carney & Kantowitz, 1998) and CAS (Lerner, Kotwal, Lyons, & Gardner-Bonneau, 1996) are important tools for system designers.

In particular, the ATIS guidelines were developed over a five-year period and are built upon comprehensive task and function analyses, analytic and empirical evaluation of driver acceptance, and substantial new laboratory and on-road empirical studies focused on the needs and capabilities of drivers who use ATIS in their vehicles. By following these human factors guidelines, the designer has automatically accomplished significant first-level integration within the ATIS devices. Unfortunately, there are not yet existing guidelines for higher level integration, e.g., how should ATIS and CAS be combined within a vehicle? Such guidelines are badly needed and should be a high priority for future research.

Levels of Information System Integration

As implied above, drivers of the future will have access to a wide variety of information subsystems. For these subsystems to be effective, the information within each of subsystems will need to be consistent with each other and with the world on the other side of the windshield. Table 2 contains a conception of the levels as well as selected elements at each ITS information level. The following subsections describe some of the integration issues at different levels starting at the highest information level (i.e., the system level) and proceeding to the lowest level (i.e., the subtask level). As we proceed down through the various information levels, we will only expand on the top element in each information level. (See Table 2 for graphic representation of the ITS information levels.)

System Level - Travelers will access information from various sources that represent a variety of media and modes. Within a given day, travelers might obtain information from such sources as kiosks, personal computers (at home or in the office), in-vehicle displays while stopped, parked, or in-transit, and variable message signs on the highway. When appropriate, it is important that such aspects as terminology, data presentation and format, input method, and symbology be consistent and supportive or, at a minimum, non-interfering, to provide the appearance of one system to the user.

Subsystem Level - Drivers will have access to a diversity of in-vehicle information categories. Navigation information could include area maps, turn-by-turn directions, and time-to-arrival estimates.

Table 2.
Examples of Elements Across Information System Levels

ITS Information Levels				
Subtask	*Task*	*Component*	*Subsystem*	*System*
• Selection criteria preferences	• Route selection	• Navigation	• ATIS	• In-vehicle
• Destination entry	• Route following	• Routing	• Safety	• Kiosks
• Route confirmation	• Route re-selection	• Real-time traffic congestion	• Convenience	• Portable computer
• Select map scale		• Safety advisory	• Collision avoidance	• Variable message signs
				• Cell phone
				• On-the-road signage
				• Highway advisory radio

Safety oriented information might provide the driver with knowledge of vehicle stability, vehicle diagnostics, obstacle/pedestrian detection, and cargo status. Convenience oriented information could present information as transit schedules, toll collection transactions, weather, and "yellow pages" contents. These subsystems must be integrated with the driving environment to determine when the driver can receive the information. That is, should the driver be able to access information about restaurants in heavy or light freeway traffic or should the driver be restricted to using that function while parked?

An important aspect at this level involves integrating two or more subsystems. Crash avoidance information and other in-vehicle information subsystems can be optimized individually. However, this is done at the peril of driver acceptance of the entire system. Gagné (1962) pointed out that when subsystems are optimized independently of each other, the total system may very well be suboptimal. Figure 1 illustrates the sequence of in-vehicle information subsystems. Early in the sequence we have a traffic advisory information later followed by collision avoidance information. The former subsystem may very well have an affect on the latter subsystem. The more poorly designed the traffic advisory information system is, the more the collision avoidance subsystem will be activated. Frequent activation of the collision avoidance system may affect driver acceptance of such subsystems and/or acceptance of the totality of the subsystems. In other words, frequent activation may be considered a nuisance even though the information provided by the subsystem/system is highly safety relevant. It would be unfortunate, and most improbable, if drivers were to accept the fact that weaving in and out of one's lane is the price one has to pay for using a traffic advisory information system.

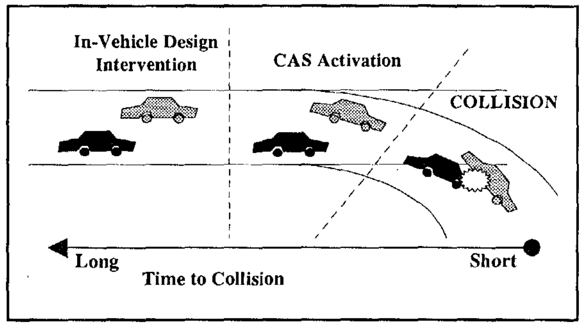

Figure 1. The influence of a traffic advisory information subsystem on a collision avoidance subsystem.

<u>Component Level</u> - When using navigation systems, there is a variety of subsystems to consider. For instance, drivers can obtain information on navigation, routing, real-time traffic, and safety advisories and warnings. At this level the integration concerns are the uniform ways of reporting the information and prioritization of messages as well as interrelating the information between subsystems. That is, routes that are suggested by the system and accepted by the driver should, in a fully developed subsystem, take into account real-time traffic conditions and safety advisories thus providing the driver with a consolidated understanding of the current situation.

<u>Task</u> - Providing routing information involves several potential tasks. Among these are selection of

route, following route instructions, and reselection of route in instances, for example, when there is an accident ahead. The emphasis at this level is on designing the task sequences so that the individual and combined tasks don't take an inordinate amount of time to complete and that they flow logically requiring little or no effort to know where the driver is in the task sequence.

Subtask - Selecting a route includes several aspects. For instance, the driver might have to choose selection criteria (e.g., minimal time, shortest distance, or avoid freeways where possible), enter destination and possibly interim destinations, and confirmation of selected route. As in the previous level (i.e., the task level) these subtasks must be integrated so that they do not take an inordinate amount of time to complete and that they flow logically requiring little or no effort to know where the driver is in the subtask sequence.

SAFETY AND SYSTEM INTEGRATION

One problem in using accident databases to determine highway safety is that accidents are binary events: on any given trip an accident either did or did not occur. This implies that any trip completed without an accident is a safe trip. However, from a human factors perspective, error is a graded set of probabilities. Thus, it is more useful to speak of safety gradients or safety margins rather than a binary classification. An alcohol-impaired eighty-year old driver who is not wearing his eyeglasses driving 100 mph at night in a station wagon might be lucky enough to travel from point A to point B without an actual accident, but this good fortune does not imply that the safety margin for that trip was infinite.

Figure 2 shows that safety margins are derived from two opposing components. As the driver and the vehicle are more capable, the safety margin increases. As the driving environment becomes more demanding (e.g., increased traffic, poor visibility, marginal highway geometry), the safety margin decreases. Thus, the safety margin is a dynamic sum that reflects the aggregate of its two components. When the safety margin is negative, accident probability is high.

While Figure 2 is conceptually interesting, it provides little direct assistance to ITS designers. Figure 3 is a more helpful elaboration of the safety margin concept. It states that drivers have to process two streams of information concurrently. Out-of-vehicle roadway information allows the driver to evaluate the demands of the external driving environment. However, the driver must also process in-vehicle information which, given the potential for a large ITS message set (Table 1), can be substantial.

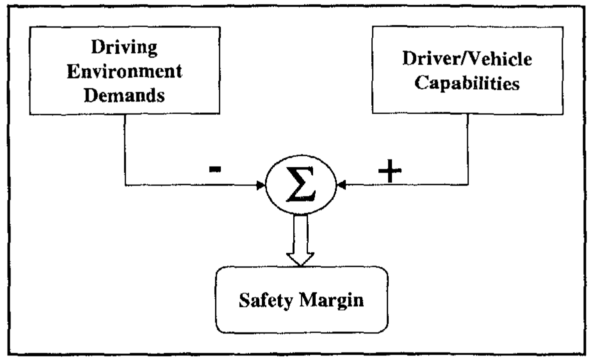

Figure 2. Safety is more than crash avoidance.

The interaction of these two streams of information within the mind of the driver is complex and difficult to characterize by only qualitative description. Designers need detailed answers about sub-system trade-offs and these are best provided from a quantitative computational model of the driver and vehicle (e.g., Levison et al., 1998, in press). Such a model then generates measures of driver/vehicle performance for specific combinations of roadway conditions and in-vehicle information loads. But even these measures are not sufficient to aid ITS designers. Knowing that the standard deviation of lane positions increases by .8 feet or that driver reaction time increases by 112 msec can help the designer make relative judgments but unless the designer knows the implications of such judgments for safety, it is still hard to make absolute design decisions. Measures of performance must be translated to measures of effectiveness (Dingus, 1998, in press). If a system designer knows that a certain increase in lane position standard deviation can be related to probabilities of a vehicle incursion into an adjacent lane (Allen, Parseghian, & Stein, 1996) that a secondary-task reaction time can be translated into a probability of a fatal accident (Harms, 1996), then meaningful trade-offs can be established. Without the kinds of calculations and translations shown in Figure 3, the safety-margin concept remains vacuous and of small practical utility.

Finally, we must also remember that all the items inside a vehicle have the potential to increase driver workload, even if they are not part of the specific ITS items being designed. So-called convenience items, such as radios and cellular phones, also affect the safety margin by providing

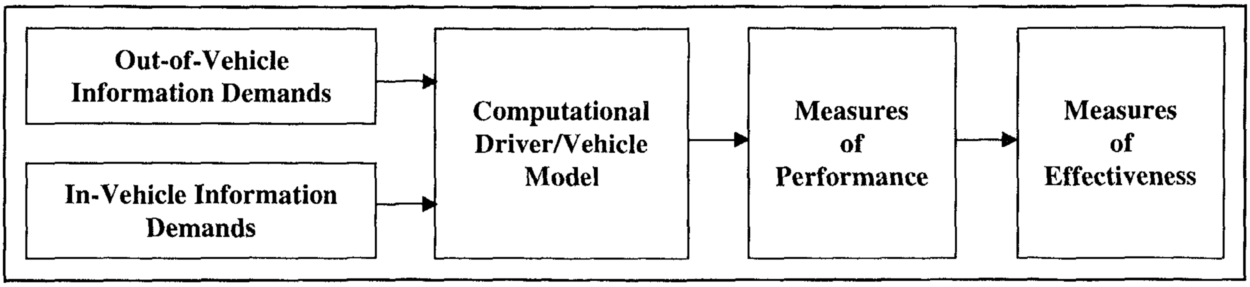

Figure 3. Safety is a system characteristic.

increased demands of in-vehicle information. In a fully integrated system, all these devices would be interconnected and messages would be prioritized and regulated to prevent driver overload. Until that happy day, ITS designers must leave some safety margin for the driver to process in-vehicle information from non-integrated in-vehicle systems.

While a major ITS goal is to increase the safety margin, paradoxically, new advanced technology if poorly implemented can have the opposite effect and make driving more dangerous. The driver can process much less information per unit time than technology is capable of presenting. A system designer who tries to maximize the information his system sends, perhaps in order to obtain a competitive advantage over other ITS products, may be decreasing the safety margin. While human factors experts understand driver limitations in a general way, much more specific research is badly needed before we can safely incorporate convenience items and new ITS technologies inside vehicles. Research on human factors will allow system designers to aid drivers using advanced in-vehicle technologies without decreasing safety margins.

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ABSTRACT

This paper examines copiloting as a strategy used by older drivers to compensate for some of the age-related deficits in driving skills. It also reports on an exploratory study that found that older drivers consider help of the human copilot useful in ITS navigation systems. Little is known about copiloting and since knowledge about this behavior would be valuable in developing ITS systems for older drivers, research into this topic is needed.

INTRODUCTION

Driving and navigating an automobile become more difficult as people age. There is deterioration of vision, particularly at night as sensitivity to glare increases, as well as an increase in reflex and reaction times (1). There is also a reduction in attention resources, which leads to reductions in cognition and perception (2). As people age, the ability to divide attention between several tasks decreases (3, 4), as does the ability to ignore irrelevant information (5, 6). Many studies indicate that the deterioration of cognitive processing due to aging has an effect on spatial ability, navigation, and way-finding skills (e.g., 7 - 11).

The elderly are the fastest growing portion of the population of the United States and the percentage of older drivers on the roads is steadily increasing. The percentage of licensed drivers who are over 70 years of age has increased from 3.9% in 1965 to 9.3% in 1994 (12, 13). Furthermore, in 1994, 75% of all adults between 75 and 79 years of age, about 62% of those between 80 and 84, and 40% of those over 85 held driving licenses. (13). These proportions are expected to increase as the "baby boomer" cohort continues its lifecycle.

An automobile in American society provides not only transportation but is important in maintaining one's independence, autonomy, and in some cases, self-esteem (14). Curtailment of driving usually means relying on others for transportation, incurring the inconvenience of public transportation, reducing trip making, and decreasing involvement in other activities. It is, therefore, not surprising that older drivers continue to drive as long as they can even though their driving skills may be diminishing. However, older drivers do employ various strategies to compensate for the effects of aging on their skills. They avoid situations that they feel are dangerous, difficult, or stressful such as driving at night, in bad weather, on limited access highways, and in unfamiliar areas (e.g., 15 - 17). They also drive more slowly and cautiously. Another strategy used by older drivers is to copilot or enlist the resources and abilities of another person in piloting and navigating the vehicle.

Recent technical advancements in the field of Intelligent Transportation Systems (ITS) hold great promise for the older driver. Systems such as in-vehicle navigation and route guidance, collision avoidance, near-object detection, intelligent cruise control, and night-vision enhancement may be able to extend the time some older drivers can safely and securely operate an automobile (18). However, it is also possible that such systems can offer more distraction and confusion and make driving even more difficult for the older driver. Whether such systems help or hinder depends on how well the needs, preferences, and abilities of the older driver are taken into account in the development and design of these systems.

The copiloting activity of older drivers appears to be a behavior that could provide valuable input into the design of ITS systems for older drivers. In-vehicle navigation systems and route guidance, in particular, are types of copilots and it seems reasonable that lessons learned from human copiloting would be useful in their development. Yet, little is known about the human copiloting practice and it has not been a consideration in ITS designs.

OLDER DRIVER NAVIGATION

What is known about the navigating and piloting performance of older drivers comes from examination of driving and navigation performance of solo drivers conducted as part of the process of developing ITS in-vehicle navigation and route guidance. Studies that compared driving and navigating performances of older drivers using standard navigation aids such as maps and written instructions against various ITS in-vehicle navigation systems, generally confirm that older drivers do not perform as well as younger drivers. These studies also find that the performance of the older drivers improves when using ITS in-vehicle navigation systems as compared with using maps or written instructions (19, 20).

Human-factors studies of ITS in-vehicle navigation have found that older drivers spend significantly more time looking at navigation displays than younger drivers (21, 22). This raises safety concerns because older drivers have been found to need to view the road for a greater percentage of time than younger drivers to maintain vehicular control (23). Walker et al. (24), studying driving and route following performance with additional task loads, found a very strong age effect on the Increase of driving performance deficits with heavy task loads. They found that magnitude of the age difference was reduced when the navigation information was presented via auditory instructions. While this has important implications for ITS in-vehicle navigation system design, it should be noted that hearing loss is extremely prevalent among older adults (25).

A recent study by Barham et al. (26) found that the overall standard of driving by a sample of drivers over 65 years of age, driving an unfamiliar vehicle equipped with an in-vehicle navigator in an unfamiliar area, was not adversely affected by the route guidance system. However, for a portion of the subjects, there was some deterioration of performance when faced with the dual task of driving and following the route guidance system's instructions.

The results of these studies indicate that the driving performance of older drivers is helped by in-vehicle navigation systems. However, they also provide evidence that some portion of the older drivers have problems hearing, seeing, and processing the information coming from an in-vehicle navigation unit.

COPILOTING

I was part of a research team that noticed the use of copiloting by older drivers using ITS in-vehicle navigation systems. We were conducting two natural use studies of in-vehicle navigation systems as part of an evaluation of the FAST-TRAC ITS project in Oakland County, Michigan (27, 28). In these studies, subjects were given project vehicles equipped with in-vehicle navigation devices to drive for one month and instructed to use them in their normal every-day driving. The subjects kept driver's logs of their trips and completed a detailed survey about their perceptions and valuations of the systems.

The two in-vehicle navigation systems were the Ali-Scout and TetraStar systems, both made by Siemens Corporation. In the Ali-Scout system, the vehicle's navigation unit communicated with a central computer via a system of roadside beacons. The TetraStar system was a stand-alone system that used GPS technology and map matching to provide guidance. Both systems provided visual and voice turn-by-turn guidance to destinations specified by the user.

A two-factor experimental design, with three age categories (19-to-29, 30-to-64, and 65-to-80) and the two sexes, was used in both natural use studies. In the first study, 102 subjects drove a project vehicle equipped with an Ali-Scout system for a month. In the second study, 60 of the original 102 subjects drove a project vehicle with the TetraStar system for one month. The differences in users' perceptions and behaviors toward the two navigation systems are reported elsewhere (28).

Analysis of the experimental data showed differences in the way the older drivers used the navigation systems, as compared to the two younger groups of drivers. Older driver trip patterns were different; they traveled at different times of day; and they tended to make more recreational trips than other drivers. They also had more problems learning and understanding the systems. However, once the oldest group of subjects learned to use the navigation units, they used them more than other drivers.

Investigation of copiloting practice was not part of the original study. However, in the interactions with the subjects, we noticed that the older drivers were likely to team up with their spouses or companions when learning and using a system. The involvement of this second person was much more evident in the oldest age group than in the two younger groups. The older drivers also tended to comment more about the location of the navigation displays, the glare on the displays, and the difficulty in seeing some of the information on the displays. It was clear that older drivers had some unique problems, requirements, and uses of in-vehicle navigation systems.

We decided to look more closely at this teaming or copiloting activity. A search of the literature revealed little. We found that copiloting was mentioned in a study of the driving behavior of persons suffering from Alzheimer's disease (29), where drivers were totally dependent on their copilot for directions and even the interpretation of traffic control signs and signals. We also inferred support for copiloting from a study of older drivers and an ITS navigation system conducted in a simulator by Mollenhauer et al. (30) where in post-experiment debriefings, subjects revealed that they rarely drove to unknown destinations by themselves. We interpreted this to mean that the older drivers prefer to make such trips with another person, or copilot.

To further explore this phenomenon, we invited the older subjects, who had participated in both natural use studies, and their spouses for group interviews to discuss how they drove when they drove alone and together, how this changed over time, and how they used the ITS navigation units. In all, 18 people participated. Their ages ranged from 64 to 82 with an average age of 72.2.

The group interviews indicated that the older subjects often used a copilot to help them overcome the challenges experienced in driving. The copilot served a number of specific functions that are consistent with the changes in perception and cognition that older persons experience as they age. One of the most common uses of a copilot described by our discussion participants was that the copilot served as "an extra set of eyes" for the driver to scan the environment for navigation cues, (e.g., landmarks, road signs) that were useful for the driver.

The discussions also indicated that copilots helped drivers compensate for declines in reaction time and increased difficulty with divided-attention tasks. The copilots provided the driver with information earlier than would be available without the copilot, thus reducing the negative impacts of increased reaction times. Put simply, the copilot may have increased the amount of time available for making a decision. The copilot also served as a second conduit of information, reducing the need for the driver to engage in divided-attention tasks. The copilot paid attention to tasks that the driver may otherwise have had to attend to, thereby reducing the attentional load required from the driver and freeing the driver to focus on the driving. The companionship function of the copilot was also frequently mentioned as an important role for the copilot.

We found that ITS in-vehicle navigation units used in our natural use studies served as copilots for older drivers to a certain extent, much like human copilots do currently. Discussion participants reported that they thought that an ITS unit was almost as good as a human copilot, but most agreed that an additional human copilot was helpful in using the ITS navigation unit. When present, it was the human copilot who monitored the navigation unit.

FUTURE DIRECTIONS

Copiloting, appears to be a compensatory behavior used by older drivers to help them overcome some of the deleterious effects of aging on driving and navigating vehicles. However, very little attention has been given to this behavior and the effects that copiloting may be having on the mobility of older persons are not fully understood. Since ITS technology is attempting to serve some of the copiloting functions, questions related to the " who, how, when, and where" of copiloting need to be answered.

Older drivers may in large part be more eager to have both the ITS unit and a human copilot together because of added difficulties associated with seeing, hearing and interpreting the information presented by the ITS unit. The human copilot provides another set of eyes and ears to perceive and interpret information presented by the ITS unit. In addition, while ITS navigation units may be able to present information to the driver, a human copilot provides a decision assist system that current ITS products cannot. The human is flexible, can respond to driver queries spontaneously and can adjust more readily and quickly to the driving and information-processing style of the driver.

ITS navigation systems can either replace or supplement copiloting functions of humans. Current evidence for older drivers indicates that the preference is for supplementing human copilots. As such, it is important that the design of such systems for older drivers consider the copiloting environment.

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ABSTRACT

Visual enhancement studies have traditionally focused on traffic situations with seriously degraded visibility conditions, such as night traffic and driving in fog. Based on accident statistics and theoretical considerations it is argued in this paper that it would probably be better from a safety point of view if the study of visual enhancement were concerned primarily with normal, good visibility conditions. Visual enhancement is however, also needed in situations with impaired visibility. Then it is better to improve direct visibility (e.g., by lighting) than to improve visibility indirectly (e.g., by radar), because in the former case the advanced human visual system may be used to its full capacity.

TRADITIONAL ENHANCEMENT OF VISUAL CONDITIONS

Traditionally (if one may talk about tradition in such a modern topic) visual enhancement means improving existing driver visibility conditions where visibility is seriously impaired. That is to say create visibility in situations where visibility without special support is very bad. Such situations include on the one hand, driving in degraded the atmospheric conditions such as fog, heavy snow and rain, or smoke. On the other hand, it includes driving in darkness, what we normally call night driving on nonilluminated roads. Combinations of these conditions are even more serious than each single one. Night driving is the most common situation in which the visual conditions obviously need enhancement.

If we stretch the concept of visual enhancement a bit we will find that drivers' visual status also comes into the picture. For instance, old drivers with degraded vision sometimes need visual enhancement in situations where other drivers have no need. Other drivers with visual diseases, such as cataracts, have much more need for visual enhancement than drivers with good visual status.

THE NEED FOR VISUAL ENHANCEMENT ALSO IN GOOD VISIBILITY CONDITIONS

It is argued here, however, that we should expand the concept of visual enhancement far beyond the traditional degraded visual situations. Visual enhancement, especially the conspicuity of other road users, is needed at least as much in normal driving situations without any visibility impairment. To begin with, there is much more traffic in daylight and therefore about two-thirds of the accidents happen in daylight. The other arguments presented to support such an expansion into normal situations are elaborated on in the following sections.

Driver Explanation of Collisions

If we analyse driver reactions and explanations after most vehicle collisions we will find that by far the most common explanation for the collision is that one or more of the involved drivers claim that they saw the other road user (vehicle, motorcycle, bicycle or pedestrian) too late or even not until the collision was a fact. Late detection of vehicle coming from an unexpected direction is in fact the most basic driver error (Rumar 1990). There may be other more complex errors and higher-order errors later in the process. But without timely detection and recognition, the probability of a collision is high. Enhancement of the conspicuity of other road users consequently would play an important role in this process.

Unnatural Detection Situations

If we analyse the driving task from an ecological point of view, we will find that our senses were developed for situations quite different from those we are facing as drivers today. Our ancient enemies, mainly predators and other humans, attacked us in a dynamic way exhibiting motion patterns to which we are still very sensitive. Our modern enemies, mainly cars, "attack" us in a motionless manner. They just slowly grow on our retina without any apparent motion. This is a situation to which our senses are not sensitive. We would benefit from some kind of visual enhancement. The significant reduction of daytime collisions as an effect of the so-called daytime running lights is a good illustration of this (Koornstra et al. 1997).

Field of Free Driving

One of the earliest, and still one of the best, driver models formulated is based on driver visual perception. Gibson and Crooks presented a model (1938), which states that one of the main tasks of the driver is to create in front of him an area of free driving. This area is of course heavily dependent of how the driver perceives the position and motion of other road users -- in other words how conspicuous they are and how their continued motion is predicted. Of course, enhanced conspicuity of the other road users and their paths is an important part of the task to create such an area of free driving.

Automatic Driving

Other driver models (e.g., Rumar 1990) state that driving of an experienced driver is self paced and basically automatic. The driver predicts what will happen and bases his actions on those predictions. Otherwise the driving process would be very slow and jerky. Only if the predictions turn out to be erroneous does the driving process become conscious and meditated as well as slow. Visual enhancement, especially of the other read users around the driver, should facilitate veridical predictions and thereby keep the driver reactions on a quick and automatic level.

Target Characteristics

The character and motion pattern of other road users should be enhanced in addition to their conspicuity. For instance, an oncoming car looks very much the same if it is running at a speed of 50 km/h as if it were moving at 100 km/h. However, in a situation when overtaking another car is considered, this difference in speed may be very dangerous. Studies have shown that drivers tend to estimate the meeting point to be half way between the two approaching cars (Norling 1963). In other words, the speed, the course, the energy of other road users could be visually enhanced. Yes, even the intentions of the other road users could be presented to the driver.

Two Visual Functions

Leibowitz and Owens (1977) postulated that there are two main visual functions involved in driving. One is mainly concerned with foveal vision and deals with detection and recognition. The other one deals with visual guidance and orientation and is mainly carried out in peripheral vision. Leibowitz and Owens argue that one of the main reasons for the high accident rate in night traffic is that drivers largely maintain their guidance vision while recognition vision is impaired. Therefore they underestimate the visual problems in night driving and drive too fast.

The same argument could in fact be applied to daytime driving. Drivers have an excellent visual guidance and are not aware of the fact that their recognition vision is far from perfect. The collision-reducing potential of daytime running lights is again a good illustration of the imperfection of recognition vision even in broad daylight. Consequently, visual enhancement of other road users to improve driver-recognition performance should be good.

VISUAL ENHANCEMENT IN CONDITIONS WITH IMPAIRED VISIBILITY

This expansion of the need for visual enhancement into the region of normal driving in no way reduces the need for visual enhancement in impaired visual conditions such as fog, falling or whirling snow, heavy rain, smoke, or darkness. In one way, visual enhancement in impaired-visibility conditions is different from visual enhancement in normal visibility conditions. In degraded-visibility conditions, there is an obvious need also to enhance the visibility of the road itself, not only other road users and other obstacles. This need is , as was stated above, considerably smaller in normal visibility conditions.

Judging from the hypothesis mentioned above presented by Leibowitz and Owens (1977) it is, however, questionable if visual guidance should be enhanced when in degraded visual conditions. Rumar (1990) presented ideas along the same line when he stated that driving is a self-paced task. Maybe the self pacing is made primarily on the basis of visual guidance.

There are studies recommending that we should be cautious with improving visual guidance in night driving too much. That might even lead to impaired safety. Kallberg (1993) showed that improving visual guidance at night by means of retro-reflective side-post delineators was followed by an increase of speed and an increase of injury accidents.

Initially it was mentioned that visual enhancement could even be personal. The idea could be compared to tailoring the controls of a car to the specific disability of an individual driver. The same could be done for drivers with some visual impairment. Such an application could very well be the initial step in the introduction of visual enhancement because the number of cars to treat would then be limited.

PROBLEMS ASSOCIATED WITH VISUAL ENHANCEMENT

There are a number of problems associated with visual enhancement independent of whether the driving situation is normal or particularly difficult from visibility point of view.

Unbalanced Visual Enhancement

If some stimuli or some characteristics of specific stimuli are enhanced, it implicitly means that some other stimuli or that some other stimuli are not enhanced, or at least not enhanced as much. In other words, the natural relation between the intensity of various visual stimuli is changed. Now if that is done in a correct way, balancing the stimuli intensity between the various stimuli, it is exactly what we would like visual enhancement to do -- enhance the whole scene. But if it is done by increasing the intensity of one group of stimuli at the expense of another group, it may cause serious conscious or unconscious misunderstandings in the driver and result in behavioral errors.

The previously mentioned results from studies of the safety effects of retroreflective side-post delineators in Finland (Kallberg 1993) indicate this risk. The enhanced visibility of the road, the improved visual guidance, made the drivers increase their speed and thereby decrease their safety instead of increasing it. One explanation of these results is that the visual guidance of the road was enhanced but the visibility of obstacles and road surface was not enhanced. The existing unbalance was enhanced.

Direct and indirect visual enhancement

Visual enhancement may be achieved by enhancing the direct-visibility situation (e.g., by improved vehicle lighting or by daytime running lights) or by enhancing the targets indirectly (e.g., by infrared light or radar). In the first case (direct enhancement) the human visual system and visual processing are used in the traditional way. The targets out there are just made more visible. They still compete on the same playing ground.

In the second case (indirect enhancement) the rays that enhance the scene in front of the driver are not visible to the human eye without any support or amplification. Either the driver will have to wear special glasses or he will have to watch a screen or a display. This is a weak point in such designs. Even if the image is projected on the windshield in the line of vision of the driver (by means of head-up displays, or HUD) it may compete in a distracting way with the external stimuli in the traffic scene. If the image is not projected in the line of sight of the driver, he has to move his eyes from the traffic scene, and the distraction risk is obvious. In indirect visual enhancement, the targets do not compete on the same playing ground.

Furthermore, the system safety (technical reliability) will most probably be considerably smaller in systems based on indirect visual enhancement. Another problem with indirect visual enhancement is that it will have to solve the impossible problem of choosing between false alarms and detecting misses. Also, the integration of visual enhancement systems with other advanced intelligent transportation system (ITS) in the car would be much more simple if visual enhancement would be based on direct vision enhancement. System integration is in fact an overlooked but very serious problem in the future development of ITS.

CONCLUSIONS

The first conclusion is that visual enhancement is probably more needed in normal driving conditions that in situations where the visual conditions are impaired.

The main reasons are:

- Normal visibility conditions are much more common and therefore most of the accidents happen in normal visibility situations.
- Drivers claim late detection as the main reason for daytime collisions.
- A number of theoretical arguments support this idea.

The second conclusion is that visual enhancement is a delicate task where it is very important that the balance between the various stimuli and targets must not be unduly disarranged or even enhance. Then safety may be reduced instead of improved.

Furthermore, direct visual enhancement seems to be far superior to indirect visual enhancement. The direct visual enhancement makes full use of the fantastic analysing capacity of the human visual system and avoids the potential risk of hazardous distraction and difficult system integration.

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INTRODUCTION

Over the past 100 years, the motor vehicle has had enormous influence on economic growth and social development. However, the motor vehicle has also produced social ills. It continues to be a major cause of death and injury and this is expected to increase as the level of motorization increases in established as well as emerging economies. By the year 2000, it is projected that there will be one traffic fatality and 50 injuries per minute on the world's roads. Thus, motor vehicle safety is an urgent global issue.

It is widely acknowledged that human factors are implicated in 70-90% of motor vehicle crashes. Traditional approaches to human factors research emphasized the driver as a system component. The early emphasis on human-machine cybernetics reflected a view of driving as a continuous closed-loop process. Control-theoretic models were proposed in an effort to optimize overall vehicle performance. Later refinements incorporated concepts of open-loop driving; however, the primary task of the driver remained the control of vehicle speed and lane position.

In recent years, automotive technologies have reflected advances in information and communication technologies. The intelligent driver interface (IDI) is a good example of an area of application receiving a great deal of attention in Europe, Japan and the USA. IDI's are being developed to incorporate features such as, vision enhancement, active steering and braking, adaptive cruise control, adaptive dynamics, route guidance, driver performance monitoring, collision warning systems, warnings of running-off-the-road, and other systems. They will present more information, incorporate more functionality, offer better user support and require more user interaction.

Near-term ITS will continue to require the active participation of the driver. Some critics contend that on-board systems will prove too complex, too demanding, and too distracting for users. They argue that intelligent technologies can lead to loss of skill, increased driver error, and, as a consequence, lead to greater risk of collision.

A major feature of Transport Systems (ITS) concepts is the close coupling of vehicle and infrastructure elements in an effort to achieve environmental and mobility benefits. That is, on-board systems will rely increasingly on the integrity of vehicle-highway communications and information received from external sources (such as traffic control centres). The implication is greater emphasis on macroergonomics considerations.

Although the role of human factors in system effectiveness and safety is widely acknowledged, there is little evidence of the application of human-centred approaches in modern designs. It must be clearly understood that technology itself is not inherently beneficial or detrimental. Safety depends on the design and functionality of the interface and its integration with other elements of the system. In other words whether new technologies will succeed in solving our future transportation problems or not depends primarily on human factors.

Intelligent driver interfaces will increase the complexity of the driving task and create the need as well as the possibility for adaptive technologies. On the one hand, new technologies expand the solution space beyond conventional boundaries. On the other hand, the solution selected must be optimized with respect to usability, suitability, safety and user acceptance. Four principle considerations characterize the nature of the problem and, by inference, the focus of future human factors endeavors (Noy, 1997).

Increasing complexity

The increasing complexity of the interface requires that we understand and develop computational models for complex human-system interactions. We currently lack adequate theory to ensure that IDI designs are appropriate within the context of the evolving driving task. Current efforts to generate human factors design guidelines based on empirical data are important in addressing immediate needs. However, they are inadequate in the medium to long term because they will not yield a coherent body of knowledge of human response and adaptive behaviour in traffic. Computational models based on sound theory would be far more valuable and usable by designers.

Adaptive, friendly interfaces

The work by Michon (1993) and others have clearly demonstrated the need for driver interfaces that adapt to human and traffic circumstances. Techniques will be required to adapt interfaces to individual differences in mental models and driving styles. Moreover, the adaptive interface will need to reveal the human side of technology to be accepted and used effectively. Issues such as privacy, trust in system integrity and value, and system usability will require innovative approaches. Finally, stronger societal values favouring inclusion of individuals will increasingly demand that systems be designed to accommodate all drivers, not just 95% of the population. This is most evident in the recent controversy over the risk that current air bag systems pose to short females.

Emphasis on cognition

The role of driver cognition in traffic safety has been widely recognized for some time. Treat et al., (1979) have performed an in-depth analysis of human causes of accidents. Like other studies of human error, they reported that driver error was involved in 70% to 90% of collisions. However, unlike most studies, their data permitted analysis of the root causes. Their analysis revealed that recognition errors were involved in at least 41% of driver errors and that decision errors were involved in at least 29% of driver errors. All other categories of human errors were minor in comparison to recognition and decision errors. These results signify that limitations in human information processing are the most prevalent driver errors.

Current IDI trends towards greater automation and greater use of information technologies demand much greater emphasis on understanding driver cognitive factors than is currently evident. The proliferation of auxiliary instrumentation (e.g., navigation displays) is especially problematic due to the greater potential for interference between operational-level cognitive requirements and higher-order, strategic-level cognitive requirements (Kantowitz, 1997). A black box model of the human driver is no longer adequate to address the emerging needs of system designers (Thierry et al., 1996). Designers need models of the human information processing system that will predict driver decision-making, situational awareness and strategies for negotiating in traffic. Dialogue management, compatible with driver mental models and based on knowledge of driver cognitive behaviour, is a key microergonomics issue.

Macroergonomics

Hendrick (1994) describes macroergonomics as a top-down sociotechnical systems approach to human-system interface design. At least conceptually, this means that all aspects of the transportation systems must be considered at each level of design. For example, from a macroergonomic perspective the design of an in-vehicle information display requires not only optimization of the driver interface but the interfaces of all other persons who are directly or indirectly involved in the generation, transmission and use of the information, including, for example, operators in the traffic control centres, inspectors, system maintainers, and police enforcement officers. The more tightly coupled and integrated the traffic system, the greater the need to get the macroergonomics right. An ITS system may be optimized at the microergonomic level, but if it is not also optimized at the macroergonomic level, it may fail to provide the intended benefits, or worse, it may lead to catastrophic failures.

Macroergonomics, of course, has more far-reaching implications for transportation system design. It implies a re-examination of traffic system objectives and re-engineering system hardware, software, liveware, and institutional elements to better achieve those objectives.

A NEW ROLE FOR GOVERNMENT

The role of government with regards to transportation system operation is changing. Governments have begun and will continue to transfer their traditional responsibility for providing infrastructure to the private sector, but they will retain the responsibility for planning and overseeing system mobility and safety performance. This change in governmental role will have important implications for human factors R&D. It will create new needs within industry to solve human factors problems and it will focus government R&D efforts on mobility and safety assurance.

With respect to ITS safety, governments will have a dual responsibility; a) to encourage the development of technologies that can enhance safety, and b) to discourage technologies that have the potential to adversely affect safety. Traditional governmental approaches to safety delivery tend to be reactionary (the problem is identified in the field, possible interventions are investigated, cost-benefit analyses are performed) and are considered not fully responsive to the challenges introduced by new technologies. There is increasing recognition of the need for systematic procedures and criteria for testing the systems safety of Intelligent Transport Systems (ITS) prior to large scale market penetration (Noy, 1998).

If ITS safety assurance is to be regulated, then consideration must be given developing new regulatory paradigms. Vehicle safety regulations have evolved from design specific requirements to performance criteria in an effort to remove design restrictions and promote product innovation. However, performance criteria rely on knowledge of system functionality, a precursor which is lacking for ITS since the technologies underlying ITS systems and their functionality will vary among manufacturers and likely to be constantly re-engineered in the foreseeable future.

The ever-changing design of vehicles and its impact on the nature of driving necessitate a new approach for the delivery of motor vehicle safety. It may be necessary to think in terms of intervention at a level higher than performance requirements. At this level, system functionality remains entirely within the domain of the designer. However, the designer must perform prescribed tests to ensure that the system is usable, safe, and acceptable (Noy, in press).

CONCLUSION

It is not yet clear whether in future years motorization will continue to add value to society or whether in fact it will begin to adversely affect safety, the environment and overall quality of life. While many predict the imminent collapse of the road transportation system, others are strong advocates of technological solutions. The success or failure of future transportation systems depends on human factors having a major role in systems design and implementation. Transportation system design has to be right the first time because of the potentially huge implications of failure. It will be necessary to validate designs against usability criteria to ensure that they are readily understood, can be used accurately and reliably and generally support user tasks.

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